Nov. 4, 1941. S. A. BOKOVOY 2,261,792

QUARTZ PIEZOELECTRIC ELEMENT

Filed Jan. 2, 1940

Fig. 1.

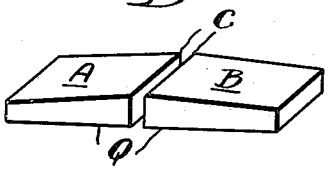


Fig. 2.

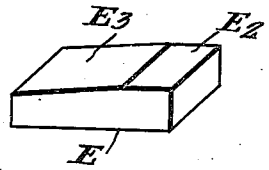


Fig. 3.

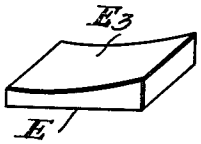


Fig. 4.

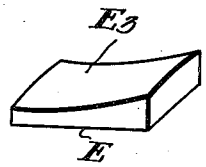


Fig. 5.

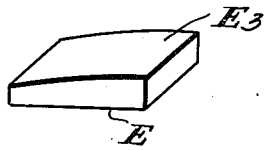
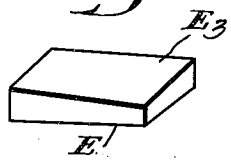


Fig. 6.



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2,261,792

QUARTZ PIEZOELECTRIC ELEMENT

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Application January 2, 1940, Serial No. 312,059

4 Claims. (Cl. 171—327)

This invention relates to the piezoelectric art and particularly to the cutting of quartz piezoelectric resonator and oscillator elements of the type designed to be vibrated at a frequency which is a function of the thickness dimension.

The present invention constitutes an improvement over the invention disclosed in copending application Serial No. 270,886 to the same inventor, filed April 29, 1939.

In the case of both thickness-mode and "length-breadth" or "contour" mode quartz crystals, several modes of vibration may be present and, as a consequence, the crystal blank or element may be vibrated at several different and apparently unrelated frequencies. This, of course, is undesirable, especially where the several frequencies are quite close to each other, in which case the operator may unwittingly cause the crystal to be vibrated at a frequency other than that at which it was designed to operate. This difficulty may be obviated in the case of a contour-mode crystal by so proportioning the length and width dimensions of the element that it will vibrate at only one of the several contour-mode frequencies normally present when a random relation exists between the length and width. As to this, see U. S. Patents 2,064,288, 2,073,046, 2,111,383 and 2,111,384.

The problem, as it relates to thickness-mode crystals, is not susceptible of the same solution and is apparently far more complex, since in such crystals there are present not only frequencies which are characteristic of the several thickness modes of vibration, but there also exists various spurious and apparently unrelated frequencies which may be said to constitute a "secondary spectrum of responses." Each mode in the thickness family of modes appears to have its own family of secondary responses; in any event a secondary response exists irrespective of the orientation at which the crystal blanks are cut from the mother crystal.

Several theories may be advanced for explaining this characteristic difference between contour-mode and thickness-mode crystal elements. By way of example: (*a*) The usually greater activity of a crystal when vibrated at a thickness-mode frequency may bring out what would otherwise be highly damped motions in the quartz. In this connection, it is apparent that a very weak response not noticeable when a low voltage is applied to the crystal may become quite pronounced with increased voltage. (*b*) Some of the secondary or spurious frequencies may be directly related to harmonic responses of lower fundamental vibrations inherently present in the quartz. (*c*) Some of the secondary responses may be related to what is commonly known as "coupling" between the desired mode of vibration and other normal modes of vibration.

The problem of attenuating spurious frequencies present in thickness-mode crystals is one that has long engaged the attention of those skilled in the art and some small measure of success has been achieved by adopting very exacting standards in the cutting and finishing of the crystal blanks. By way of example: a crystal blank whose major surfaces are substantially optically flat and whose minor surfaces are at precisely a right angle thereto has heretofore been thought to exhibit fewer and less pronounced spurious frequencies than one cut to less exacting standards. It has also been thought that, when the length and breadth dimensions of thickness-mode crystals are as small as possible, the spurious or secondary responses are less pronounced than in the case of similar larger crystal elements. These expedients, however, have never achieved wide commercial success either because of the increased manufacturing costs incident to the achievement of duplicate parallel optically-flat surfaces, or because it is extremely difficult to clamp a very small thickness-mode crystal without excessive damping.

Accordingly, the principal object of the present invention is to provide a thickness-mode piezoelectric element which is free from spurious frequencies approaching that of the fundamental thickness-mode frequency at which the said element is designed to be operated, and one characterized by its simplicity of manufacture and its economy of material.

Other objects and advantages will be apparent and the invention itself will be more readily understood by reference to the following specification and to the accompanying drawing, wherein:

Fig. 1 is a view in perspective of two quartz crystal elements which have been cut in accordance with the present invention from one of the elements disclosed in copending application Serial No. 270,886.

Figs. 2 to 6 inclusive are views in perspective of four quartz elements cut in accordance with the principle of the invention to exhibit a substantially unitary freedom for their thickness-mode of vibration.

Like reference characters designate the same or corresponding parts in all figures.

The copending application above referred to discloses that a unitary freedom for the thick-

ness-mode of vibration may be achieved by so cutting a quartz slab, blank, or plate that at least one of its electrode faces is beveled, inclined or slants off in opposite directions from a line or area of maximum thickness adjacent the center of said electrode face.

The present invention is predicated upon the discovery that the same desirable characteristic is achieved in a quartz element wherein the line or area of maximum thickness comprises or is adjacent to an end zone, instead of the center of the crystal. Thus, referring to Fig. 1, when a crystal Q which was cut in accordance with the said earlier disclosure was divided into two parts A and B with the area of maximum thickness C adjacent an end zone of each part, and properly finished, both parts proved to be substantially free from spurious frequencies approaching a desired fundamental thickness-mode frequency. This phenomenon has been found to exist substantially irrespective of the length and breadth dimensions of the finished elements, so that it is possible to provide crystals of various sizes for particular uses and for holders of standard sizes.

The present invention is applicable to quartz crystal blanks of various orientations. It is preferable, however, to start with a blank which has been so cut with respect to the natural axes of the mother crystal that it will exhibit a zero or some low temperature coefficient of frequency when vibrated at a frequency characteristic of its thickness dimension. Such orientations are described, by way of example, in British Patent No. 441,438 (1936). The blank selected for finishing may be square, triangular, oblong, circular, elliptical, or other shape, and of any convenient dimensions suitable for the particular type of mount or holder with which the finished crystal is to be used.

In the event that a plural frequency element is desired, the blank should preferably be initially so proportioned, for example, in the manner described in U. S. Patents 2,064,288, 2,073,046, 2,111,383 or 2,111,384 that it will exhibit a unitary freedom for its contour-mode of vibration.

The unfinished blank at the outset should, in any event, be somewhat thicker than is calculated (from the thickness-mode constant peculiar to blanks of the selected orientation) to be necessary to obtain the desired thickness-mode frequency in a finished blank having duplicate parallel electrode faces. In carrying the invention into effect with such a blank, one of the major or electrode faces E (Fig. 2) surfaces is selected as a reference plane and is rendered optically flat, or nearly so, by any of the known methods of grinding and lapping. The blank may then be mounted in a clamp with its unfinished surface slightly askew with respect to the axis of movement of the grinding wheel or other instrument, so that the part to be beveled is presented to the wheel.

Instead of using a clamp and grinding wheel, the blank may be placed, with its unfinished face down, on a surface upon which a grinding compound has been spread and then manually lapped by simply confining the lapping force exerted by the operator's fingers to the end zone which is to be beveled or ground away.

It is this "slanting off" or "beveling" operation which results in the attenuation or entire disappearance of the secondary response spectrum. During the beveling operation, the fundamental thickness-mode frequency will be increased because the effective or overall thickness of the blank is decreased. (Conversely, for practical purposes, it may be considered that the frequency constant K has been increased at the thicker end zone of the blank to a degree determined by the angle or depth of the bevel.) In order to attenuate the spurious frequencies to a high degree, it is usually necessary to alter the bevel angles during the grinding operation. If freedom from spurious thickness-mode frequencies is achieved before the exact desired frequency response is reached, the lapping may be continued, taking care not to substantially alter the bevel angle until the exact desired thickness-mode frequency is achieved. Alternatively, a narrow area E2 (Fig. 2) adjacent the line or region of maximum thickness may be ground down to further reduce the effective thickness of the blank until the desired frequency is obtained. In cases where a relatively large change in frequency is desired after the blank has been freed of spurious responses, it may be necessary to change the bevel angle as the thickness, adjacent the thicker or "frequency determining" end of the blank, is reduced.

It is not possible to lay down any specific rule as to exact bevel angles required to free the crystal blanks from spurious frequencies. This is so because the bevel angles change not only with orientation and with frequency but also with the area of the blanks. Further, it appears that freedom from secondary responses may be achieved in a given blank at several bevel angles which may or may not be exact multiples of each other. Having the above factors in mind, it may nevertheless be said that the depth of the bevel in a slab of ordinary dimensions cut at any of the known low temperature angles need not exceed one-half of the thickness of the slab and will ordinarily be of the order of one-quarter of the thickness of the finished element.

The crystal blanks of Figs. 2 to 5 inclusive are parallelepipeds in which one of the limiting planes (i. e., the "top" plane) has been replaced, in accordance with the invention, with a beveled face E3 which slants off from an end zone area or line E2 of maximum thickness. Oblong or square shapes are preferred to circular or elliptical shapes in cases where the greater dimensions of the blank are to be so proportioned (for example, in the manner disclosed in the previously identified U. S. patents) as to endow the finished elements with a unitary freedom for their contour-mode of response.

Fig. 2 shows a finished element having a plane face E2 which caps the slanting face E3. As previously described, a cap face may be provided in instances where freedom from spurious frequencies is achieved before the exact desired thickness-mode frequency is obtained.

The following is a detailed description of the particular quartz piezoelectric element illustrated in Fig. 2.

Orientation.—25° W, 35° V^n. That is to say, the flat electrode face E is normal to an axis (W) which is 25° removed from an electric (X) axis and is inclined 35° from the optic (Z) axis in a direction towards parallelism with the plane of a minor (n) apex or cap face of the mother crystal.

Dimensions.—Length .638", width .288". Width of area (E2) of maximum thickness, approximately, .138". Thickness at the end zone E2 approximately .0133". Thickness measured at opposite edge, .0112".

Frequency.—4,940 kilocycles.

Electrodes.—Silver plating covering the en-

tire surface E2 and extending along one long marginal edge of the beveled face E3. On the "bottom" electrode face E, the plating covered the opposite long marginal edge and the area in register with the top surface E2.

This crystal was entirely free from spurious frequencies within a range of ±50 kcs. of the fundamental frequency (4940 kcs.) when employed in a filter circuit wherein the voltages applied to the electrodes was upwards of 50 volts. The pattern or indeed the type of electrodes employed is immaterial as far as the practice of the invention is concerned and will ordinarily be selected with a view to the capacitance and other electrical characteristics required in a particular circuit.

It is not essential to the practice of the invention that the beveled area E3 comprise a plane uniformly tapered surface. Indeed, when the grinding is done manually, it is practically impossible to achieve a perfectly plane or uniform surface, particularly where a very thin (high frequency) crystal blank is employed, since in this case the crystal is quite flexible. This is indicated in Figs. 3 to 6 inclusive where the beveled surfaces E3 are of various contours.

In Fig. 3, the beveled surface E3 is slightly concave in the long dimension.

In Fig. 4, the beveled surface E3 is slightly concave in the long dimension and slightly convex in the width dimension.

In Fig. 5, the beveled surface E3 is slightly convex in the long dimension.

In Fig. 6, the beveled surface E3 is sloped off toward the observer so that the thickness of the crystal adjacent its two thinner corners is not exactly the same.

Although certain specific ways and means for accomplishing the objects of the invention have been set forth, it will be understood that they have been given by way of example and should not be construed as limitations to the scope of the invention.

It is well known in the art that, in order to obtain a desired frequency characteristic in a piezoelectric element with the precision that is required, frequent tests should be made between successive stages of the grinding operation. The invention is, therefore, not to be limited except insofar as is necessitated by the prior art and by the spirit of the appended claims.

What is claimed is:

1. Method of cutting a piezo-electric element so as to exhibit a substantially unitary freedom for its thickness mode of vibration, said method comprising grinding one of the major surfaces of a quartz blank whose thickness is slightly greater than is required to achieve a desired thickness-mode frequency in the form of a surface which slants off from an end zone of maximum thickness, changing the bevel angle of said slanting surface until spurious frequencies related to the said thickness mode of vibration are attenuated and then reducing the thickness of said blank adjacent said end zone until the desired thickness-mode frequency is achieved.

2. Method of cutting a piezoelectric element so as to exhibit a substantially unitary freedom for its thickness mode of vibration, said method comprising grinding one of the major surfaces of a quartz blank in the form of a surface which slants off from an end zone of maximum thickness and then changing the slope of said slanting surface until spurious frequencies approaching the desired thickness mode frequency are attenuated.

3. A piezoelectric quartz element one of the electrode faces of which slants off from an end zone of maximum thickness to an end zone of a thickness substantially no less than one-half of that of said first-mentioned end zone, the angle and contour of said slanting surface being such as to endow said element with a single frequency response when vibrated at a frequency which is a function of the thickness dimension of said first-mentioned end zone.

4. The invention as set forth in claim 3 and wherein said first-mentioned end zone comprises a plane surface from the inner edge of which said one of said electrode faces slants off.

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